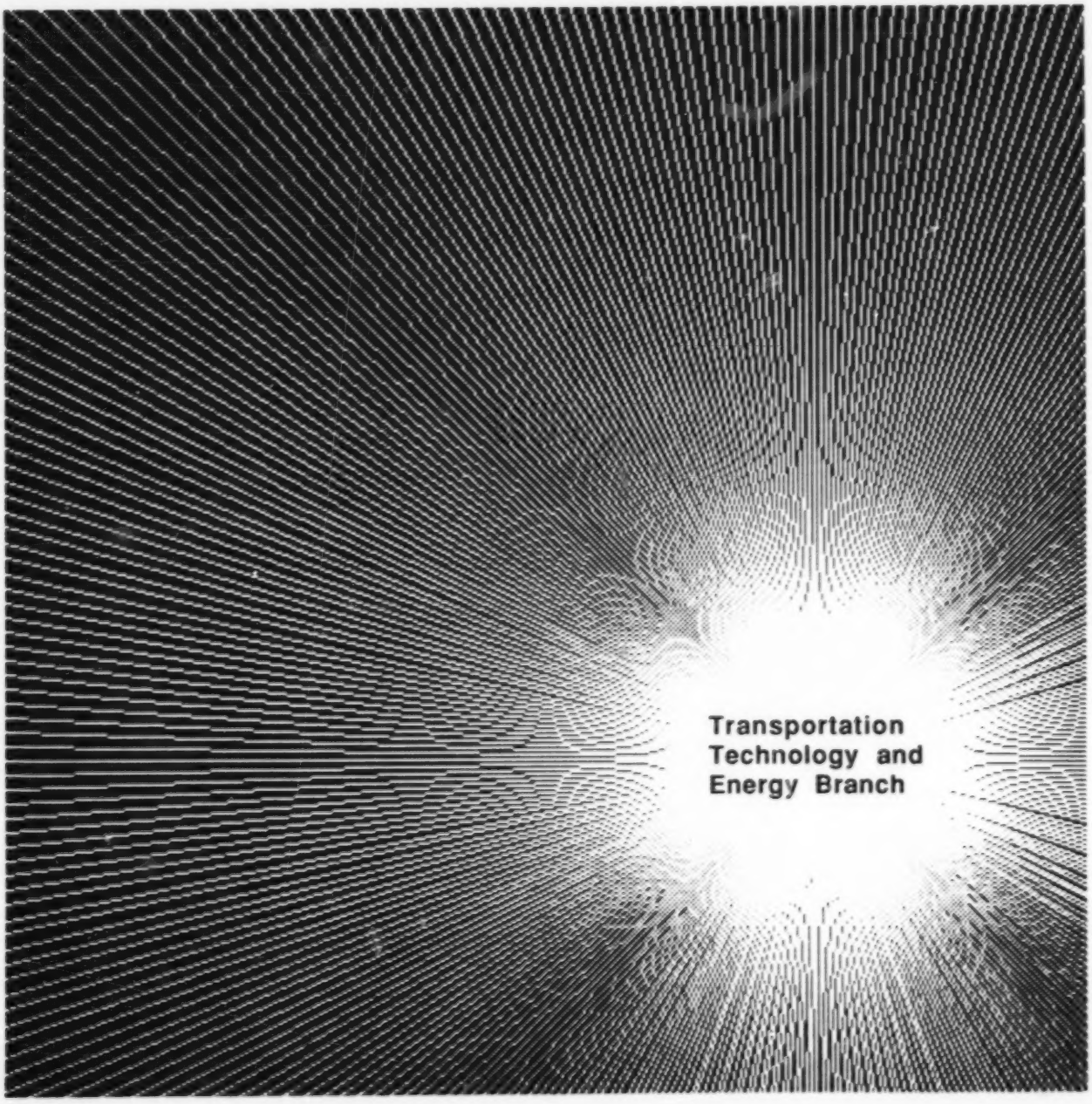
Ontario

Ministry
of
Transportation

Transportation
Technology and
Energy Branch



91-05406/

Aggregate Truck On-Board Weighing Experiment

CV-90-07

Technical Report Documentation Page

Aggregate Truck On-Board Weighing Experiment

Prepared by: **W.R.J. Mercer and J.R. Billing**

Report No.: CV-90-07

Date: March 1991

Published by: Vehicle Technology Office
Transportation Technology and Energy Branch
Ministry of Transportation

Abstract: A limited experiment has shown that fifth wheel on-board scales can assist the driver of a tractor-tri-axle semitrailer aggregate truck to determine whether the truck's axle weights are likely to conform with provincial axle weight law. This was achieved because the load on the liftable axle was properly controlled. The principal barrier to achieving correct axle load distribution in aggregate trucks appears to be getting the proper initial load distribution by the loader operator.

The two models of fifth wheel on-board scale used in this experiment proved essentially equal in most respects, and quite adequately accurate and consistent.

Key words:

Distribution: By request

Copyright Status: Crown copyright

CV-90-07

Aggregate Truck On-Board Weighing Experiment

W.R.J. Mercer
J.R. Billing

Vehicle Technology Office
Transportation Technology and Energy Branch
Ministry of Transportation of Ontario

Published by:

Transportation Technology and Energy Branch
Ministry of Transportation of Ontario

Published without prejudice as to the application of the findings. Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the ministry.

For additional copies, write:
Technical Publications (TT&E Branch)
Ministry of Transportation of Ontario
Room 321, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8
(416) 235-3466

March 1991

CONTENTS

PAGE

ACKNOWLEDGMENTS iii

EXECUTIVE SUMMARY iv

1/ INTRODUCTION 1

2/ METHODOLOGY 2
2.1/ Trucks 2
2.2/ Fifth Wheel On-board Scale Systems 2
2.3/ On-board Scale Installation 3
2.4/ On-board Scale Calibration 9
2.5/ Data Collection 10

3/ RESULTS 13
3.1/ Capital Cost 13
3.2/ Installation and Calibration Time 13
3.3/ Data 13

4/ DISCUSSION 23

5/ CONCLUSIONS 28

REFERENCES 30

ACKNOWLEDGEMENTS

This experiment was conducted by the Ministry of Transportation of Ontario under the auspices of the Government/Aggregate Industry Weight Review Committee.

The ministry acknowledges the assistance of committee members in structuring and organizing the experiment.

The ministry also gratefully acknowledges the generous supply of equipment, personnel, co-operation and assistance rendered by the following principal participants in this experiment :

Tony Cupido, President, A. Cupido Transport Ltd, and
Peter Hodge, President, Peter Hodge Transport Ltd.

EXECUTIVE SUMMARY

A limited experiment has been conducted under the auspices of the Government/Aggregate Industry Weight Review Committee to assess whether fifth wheel on-board scales could assist the driver of an aggregate truck to determine whether the truck's axle weights are likely to conform with provincial axle weight law. The experiment provided scale system costs, installation and calibration time, and scale accuracy. The experiment was of insufficient duration to allow any estimate to be made of long-term reliability, or maintenance costs. Further, no aggregate producer or carrier was prepared to consider re-distribution of load in the case where the truck was found to be out of compliance with provincial axle weight law. The time and equipment costs that would be associated with any such re-distribution therefore have not been established.

Four tractor-tri-axle semitrailer aggregate haul trucks were equipped with commercially available fifth wheel on-board scales, from two different vendors. The liftable axles on the trucks were carefully calibrated to maintain their maximum allowable load. The drivers logged truck gross and axle weights, and the on-board scale readings, over a period of about three months.

The on-board scales cost $3500-5000, depending on the make and model of the fifth wheel on the truck to which they were fitted. Installation and calibration was completed within one working day. The on-board scales were set up to provide the drive axle load of the tractor, and consistently produced almost the same reading as the ministry scale. Both vendors products performed well for the duration of the experiment, requiring no maintenance, and were judged essentially equal in most respects.

The trucks participating in the experiment achieved much better control of their liftable axle load than a sample of similar trucks with similar loads. They also had a substantial reduction in the number of potential axle overweight charges. While the on-board scales clearly demonstrated that a driver could assess whether or not the truck was in compliance with axle weight law, it is not clear how much the on-board scales actually contributed to the improved axle weight compliance.

Aggregate producers are already successfully and consistently loading trucks very close to their maximum allowable gross weight. This experiment shows that liftable axle loads can be tightly controlled quite easily by the truck operator. Load shift is not an issue in axle weight compliance. The major remaining issue for widespread axle weight compliance by aggregate haulers is simply for the loader operator to get the load in the right place in the truck, preferably on the first try. This may be addressed by training and information for loader operators. On-board scales could be one of several technologies or procedures that could support this objective.

1/ INTRODUCTION

Aggregate carriers have expressed concern that it is difficult to load trucks close to their allowable gross weight while not exceeding the allowable axle weights. The Government/Aggregate Industry Weight Review Committee was convened by the Ministry of Transportation of Ontario (MTO), so that the ministry could address these concerns co-operatively with all parties involved in the transportation of aggregates. It was suggested that trucks could be fitted with on-board weigh scales, so that the truck driver could provide guidance to the loader operator to try to achieve consistent load distribution.

On-board weigh scales of various designs have been commercially available for many years. However, accurate and reliable measurement of truck axle weights is a rather challenging and difficult technical problem. It is not surprising, then, that when the lack of incentive to use such devices is combined with common infant mortality and lack of evident payback, that they have not as yet seen widespread use in Ontario. On-board scales are however widely used by log-haul trucks in British Columbia to maximize loads within legal limits. An early evaluation of these scales was not encouraging, as the scales were found to be of poor structural reliability and prone to electrical failure [1]. The needs of the industry resulted in substantial product improvement to reflect the high loads and severe working conditions of log-haul trucks in British Columbia. A more recent evaluation found that these newer scales now not only perform quite adequately, but pay back their investment cost in less than two years [1]. The successful on-board scales in use in British Columbia are of the fifth wheel type, where a pair of load cells are mounted between the frame rails of the tractor or trailer and the bunk used for carrying the logs.

A limited experiment was designed to assess whether a fifth wheel on-board scale could assist the driver of an aggregate truck to determine whether the truck's axle weights conformed to provincial axle weight law. The experiment would provide:

1/ on-board scale system costs;
2/ installation and calibration time; and
3/ accuracy.

The time allowed for the experiment was insufficient to establish long-term reliability or maintenance costs of the scales.

No aggregate producer or carrier was prepared to consider re-distribution of load in the case where the truck was found to be out of compliance with provincial axle weight law. The time and equipment costs that would be associated with re-distribution therefore could not be established.

2/ METHODOLOGY

2.1/ Trucks

The truck configuration selected for this experiment was the tractor-semitrailer combination consisting of a three-axle tractor and a so-called tri-axle semitrailer, which has a fixed dual-axle unit at the rear and a single liftable axle ahead of the dual-axle unit, the "belly axle." This configuration was selected for three reasons. First, it is the single most common large truck used for aggregate haul. Second, the semitrailer usually has its load box set back from its kingpin, which means that it is not possible in most cases to get proper axle weights with a uniform load distribution in the box. The load needs to be piled toward the front of the box, which makes these trucks difficult to load properly. Finally, the truck is easy to instrument, because its gross weight is known from the aggregate producer's scale, and if the liftable axle is set up and controlled properly, only one more measurement (of either the tractor or the trailer dual-axle unit load) is necessary to get the complete vehicle axle weight distribution. It was therefore readily compatible with the new generation of fifth wheel load cells now used in the British Columbia logging industry, which could provide the tractor drive axle unit load.

An important part of the experiment was to gather axle weight data from the trucks on every trip. This required that they pass by one of MTO's Truck Inspection Stations equipped with a multi-platform scale system. A. Cupido Transport of Burlington, and Peter Hodge Transport of Mississauga were each able to provide two trucks for this experiment, and dedicate them to a haul that passed by the Oakville South Truck Inspection Station on the Queen Elizabeth Way. One of these trucks is shown in Figure 1. All four trucks were very similar in dimensions, tare weight, and allowable weights, as shown in Figures 2 and 3, even though they used tractors and trailers from different manufacturers.

In order to ensure that the load on the liftable axles was properly controlled over the period of the experiment, each truck operator installed a good quality air regulator equipped with a lock, where such a regulator was not already installed, so that a set pressure could be maintained reliably.

Each tractor was kept with the same trailer, and was assigned to the same driver, for the duration of the experiment.

2.2/ Fifth Wheel On-Board Scale Systems

The ministry purchased four fifth wheel on-board scale systems, two from Lodec and two from Structural Instrumentation (SI). Both systems were quite similar in design and function, and a composite of their features is illustrated in Figure 4. The measuring element of each system is a steel beam which has been strain-gauged to sense

Figure 1/ Truck Configuration

vertical loads only, and not any accompanying torsion or lateral or longitudinal loads. Each system uses two of these instrumented beams, secured by welding or bolting to the main frame rails or fifth wheel mounting plate on the tractor. The exact details of the attachment depend upon the make and model of fifth wheel used by the tractor. Fifth wheel trunnion bearings are adapted to mount on top of the beam, to provide the same ride height as the original fifth wheel.

The electrical signal from each load cell is sent by cable to a display unit mounted in the cab that provides the driver with a direct read-out of the on-board scale load. Each system provides the means not only to calibrate the system to a known load, but also to add a constant to the fifth wheel load to provide the actual load at the drive-axle unit, or any other load.

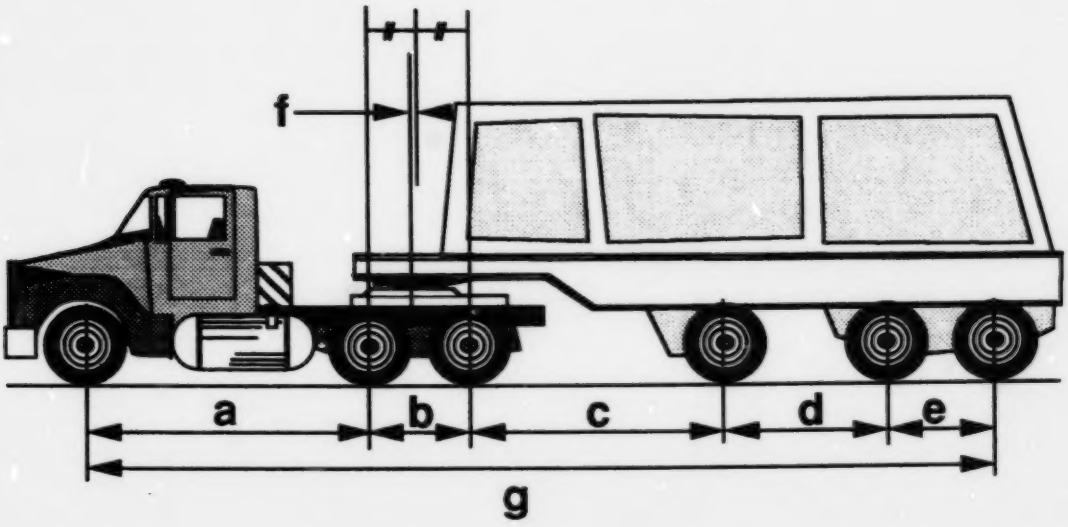
2.3/ On-Board Scale Installation

Each on-board scale system was installed by the maintenance shop of the truck owner, under the supervision of a representative of its vendor. The Lodec systems were installed in mid-January 1990, and the SI systems were installed in mid-February 1990. Each carrier took one Lodec and one SI system.

In each installation, the fifth wheel, fifth wheel plate, mounting brackets and other hardware were removed from the truck and were reworked and cleaned. The load cells were fitted and adjusted mechanically, as shown in Figure 5 for a sliding fifth wheel. Each installation required some cutting of the existing fifth wheel, principally to allow pitch clearance of the fifth wheel from the load cells and their mounting bolts. This was accomplished by notching the fifth wheel to allow for bolt head clearance, or raising the trunnion bearings to allow clearance from the load cell. In all installations, the truck operators' maintenance staff worked with the vendors' representative to achieve a workable, safe, and mutually acceptable solution to the interference problems. The fifth wheel was then reinstalled. Figure 6 shows a complete load cell installation.

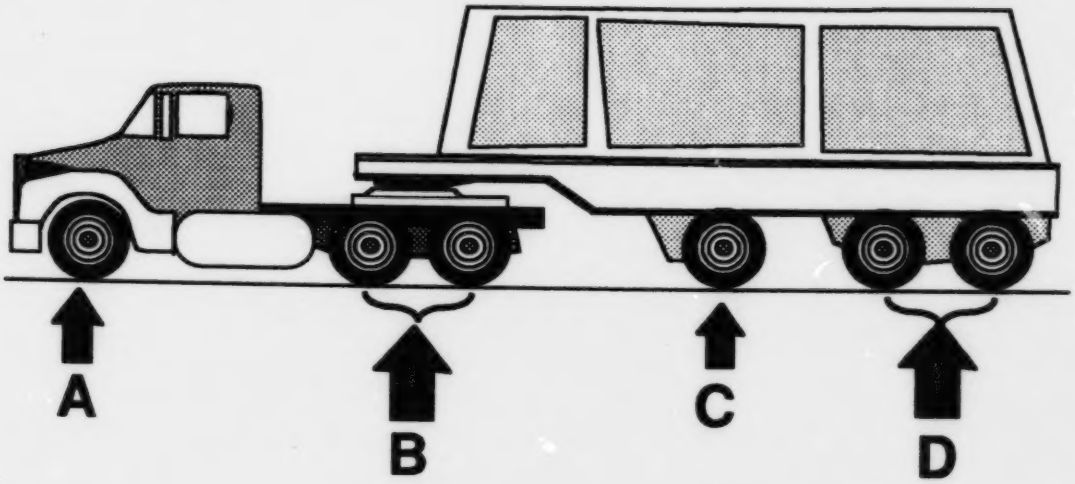
On installations where the load cells were mounted on a sliding fifth wheel, representatives from the trucking firm determined the precise locations of the slider. The settings were marked and the driver was instructed not to move the fifth wheel during the experiment. When it was necessary to move the fifth wheel, it was to be returned to its original position prior to the truck re-entering service.

The display unit was mounted in the middle of the console on top of the dashboard, as shown in Figure 7, and cables were connected to bring power to the unit and signal from the load cells to the display.



TRUCK / Scale	a (m)	b (m)	c (m)	d (m)	e (m)	f (m)	g (m)
Peter Hodge Transport / S.I	4.57	1.52	4.40	2.60	1.83	0.35	14.92
Peter Hodge Transport / Lodec	3.99	1.55	4.20	2.64	1.83	0.31	14.21
A. Cupido Transport / S.I	3.99	1.55	4.51	2.59	1.83	0.23	14.47
A. Cupido Transport / Lodec	3.96	1.55	4.46	2.59	1.83	0.23	14.39

Figure 2/ Truck Dimensions



TRUCK / Scale	TARE AXLE LOADS			
	Front "A" kg	Drives "B" kg	Trailer "D" kg	Allowable Gross (kg)
Peter Hodge Transport / S.I.	4390	7530	5760	52400
Peter Hodge Transport / Lodec	4130	7130	5640	52400
A. Cupido Transport / S.I.	5240	7240	5750	52100
A. Cupido Transport / Lodec	5290	7190	5620	52100

TRUCK	ALLOWABLE AXLE LOADS			
	Front "A" kg	Drives "B" kg	Liftable "C" kg	Trailer "D" kg
All	variable	17900	10000	19100

Figure 3/ Truck Tare and Allowable Weights

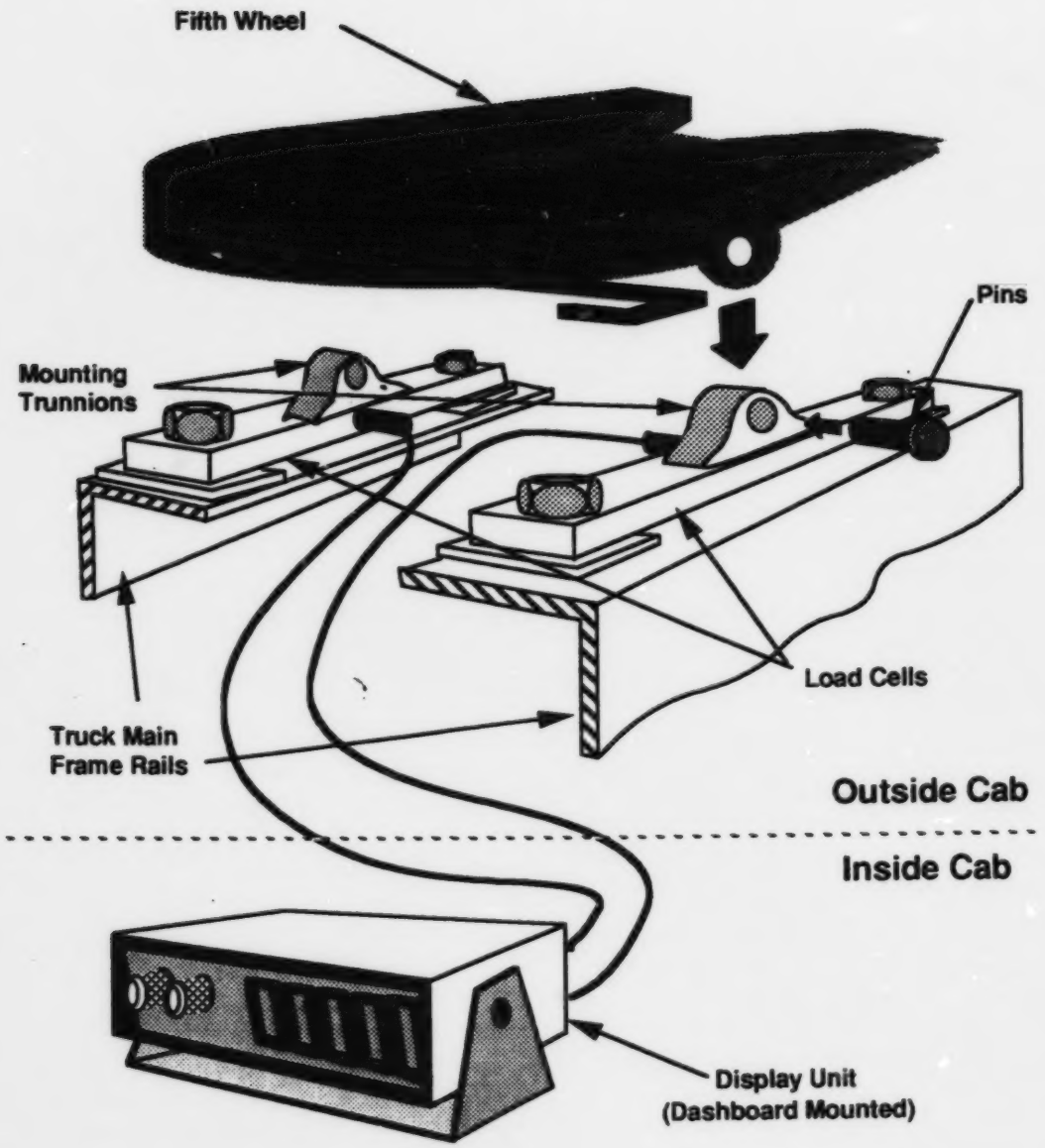


Figure 4/ Fifth Wheel On-Board Scale System

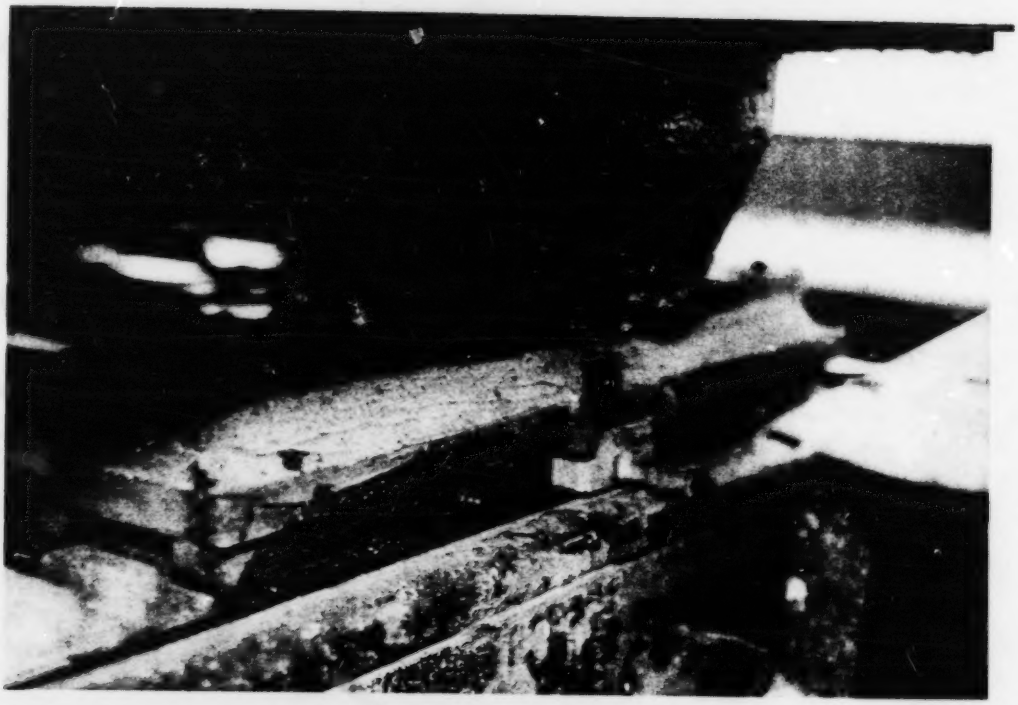


Figure 5/ Load Cell Installation

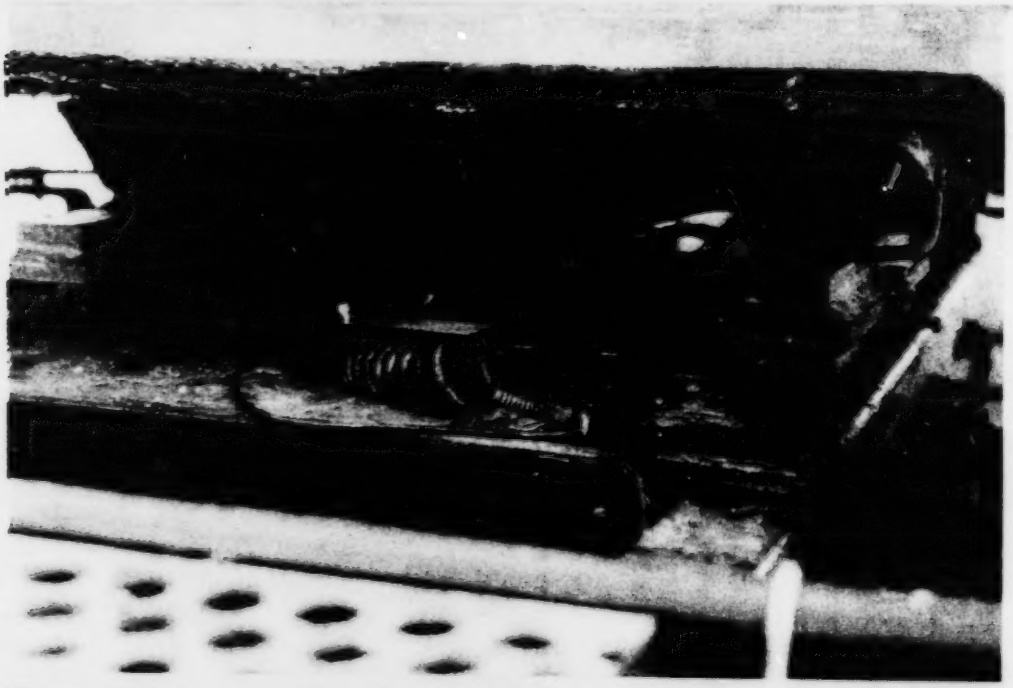


Figure 6/ Complete Fifth Wheel On-Board Scale Installation

Figure 7/ Display Unit

2.4/ On-Board Scale Calibration

After the on-board scale was installed, the truck was filled with fuel and driven to an MTO Truck Inspection Station equipped with a multi-platform scale. An inspector measured the truck, assigned it an allowable gross weight, and provided the driver with a standard form containing all this information, in accordance with current practice.

The truck was then weighed, as shown in Figure 1, and the on-board scale vendor's representative adjusted the display so that it gave the same reading as the drive-axle scale platform.

The truck was then driven to an aggregate producer, loaded, and driven back to the Truck Inspection Station. The truck was weighed again, and the vendor's representative made a second adjustment to the display so that it again gave the same reading as the drive-axle scale platform. This completed the calibration of the on-board scale

system. The display now provided a continuous read-out of the actual load on the tractor's drive-axle unit.

The semitrailer was equipped with a liftable axle, as noted above. It is the experience of ministry inspection staff that the preponderance of axle weight offences occur on trucks with liftable axles. There are various reasons for this, one of which is that the liftable axle itself is transferring an improper load to the road. If the liftable axle load is too high, this axle is overloaded directly. If the liftable axle load is too low, then either the tractor or the trailer dual-axle unit, or both, may be overloaded. It was therefore considered important to try to control the liftable load as tightly as possible, in order to allow the driver the greatest possible opportunity to realize the value of the on-board scale system. If the liftable axle load was not controlled accurately, the driver would not know whether the on-board scale reading was due to an error in the liftable axle load, or because the payload was not distributed properly.

The liftable axle load on the semitrailer was therefore calibrated while the truck was still on the ministry scale. The air regulator on the liftable axle was adjusted until a ground reaction of 10 000 kg was measured by the ministry scale. This process was fairly time-consuming, as the axle load control system responds fairly slowly and it is easy to over-correct. Once the correct load was achieved, the air regulator was locked in place at the set point. This process was possible, because aggregate trucks almost exclusively travel either empty or fully loaded. For this configuration, the liftable axle is best set at its maximum allowable load of 10 000 kg, and simply raised and lowered as the load condition of the truck requires.

The on-board scale system was now installed, calibrated, and fully functional and the truck was set up for the experiment. It delivered its load, returned to revenue service, and the data collection phase began.

2.5/ Data Collection

Data were collected from log sheets provided by the ministry and completed by the truck drivers.

The ministry and the vendors provided information on how to use the on-board scale. The ministry also provided a load and balance chart, to assess whether the truck was loaded to meet the axle weight law. A typical load and balance chart is shown in Figure 8, annotated with a sample calculation. After the driver had obtained the truck's actual gross weight from the aggregate producer's platform scale, and had lowered the liftable axle and allowed it to reach its pre-set load close to 10 000 kg, this chart allowed the driver to determine whether the truck met the axle weight law while still at the aggregate source. The driver simply determined the range of drive-axle load available from the chart for the truck's actual gross weight, and checked the on-board scale to find out whether the truck was inside or outside that range. If it was inside the range, then the axle weights were completely legal. If it was outside the range, then

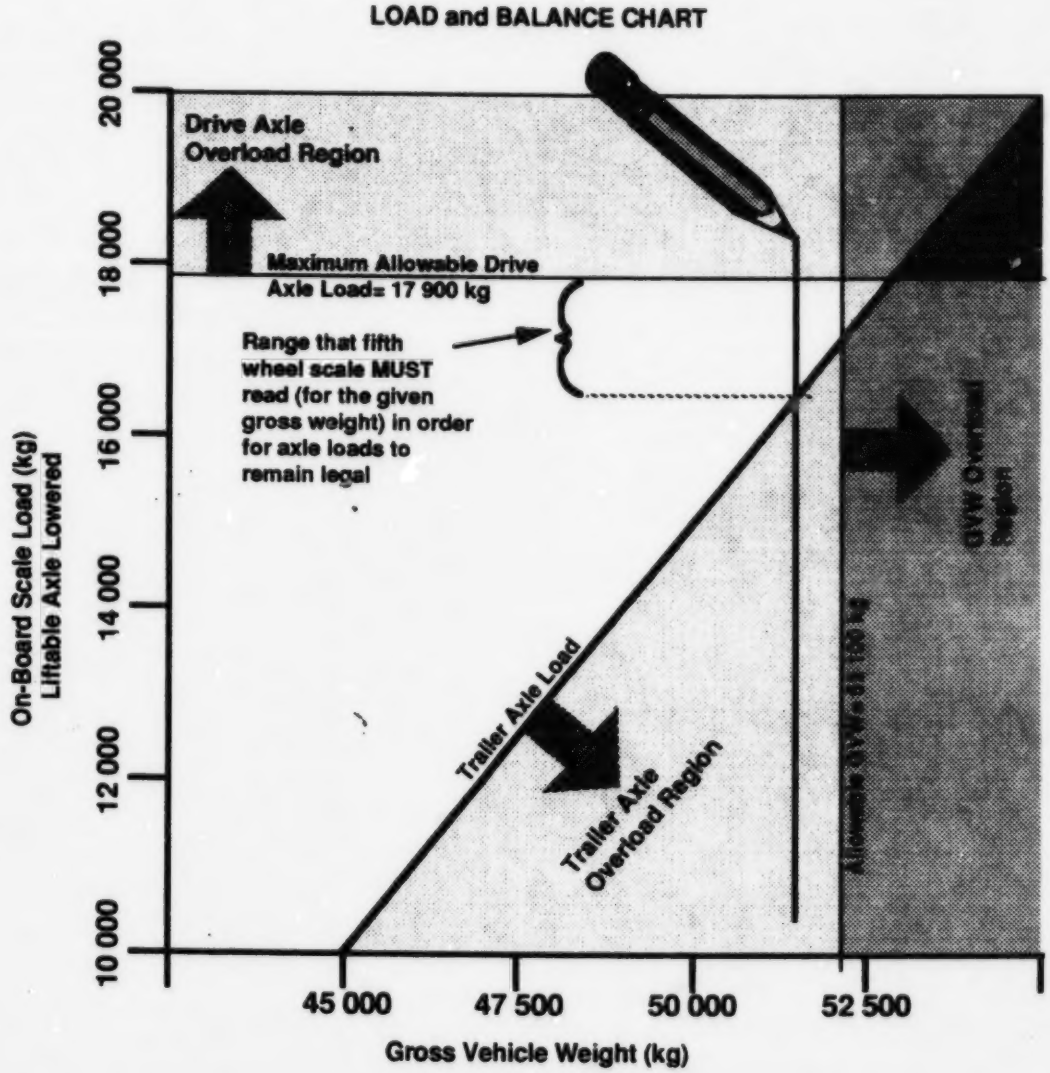
depending on the load, either the tractor drive axles or the trailer dual-axle unit were overloaded. This approach and the load and balance charts were customized for each truck participating in this experiment, and are based on the assumption that the liftable axle is properly set up and controlled to provide 10 000 kg axle load, as described above.

A load and balance chart could have been constructed for use with the liftable axle raised. The approach used was preferred, though, to familiarize the drivers with the allowable drive axle load. It would also have been possible to provide the data in the load and balance chart in tabular form.

Several trips were made by each truck on most weekdays. The driver made one log entry for each trip. After loading by an aggregate producer, the driver recorded the date and the gross weight provided by the aggregate producer's platform scale. The driver also lowered the liftable axle and recorded the on-board scale reading.

The driver then proceeded to MTO's Oakville South Truck Inspection Station on the eastbound Queen Elizabeth Way. Arrangements were made for the driver to get axle weights from the multi-platform scale at this location. The driver recorded the axle weights and also recorded the reading from the on-board scale. This completed the log entry for the trip; the driver then proceeded to deliver the load.

Drivers gave the log sheets to their dispatcher weekly. The dispatcher mailed the data to the ministry using a pre-addressed envelope provided by the ministry.



TYPICAL SAMPLE CALCULATION:

Aggregate producer loads the truck and provides the driver with the gross weight. The driver then draws a vertical line on the Load and Balance Chart corresponding to that gross weight. In this case the gross is 51 500 kg. The truck is then parked on a relatively flat area and the airlift axle is loaded to 10 000 kg. If the on-board scale on the dashboard reads within the band shown on the chart, 16 500 kg on the lower end and 17 900 kg on the upper end, the truck complies with axle weight law. If the on-board scale reads above the upper limit, (17 900 kg) the drive axles are overloaded. If the on-board scale reads below the lower limit (16 500 kg), the trailer axle unit is overloaded.

Figure 8/ Load and Balance Chart

3/ RESULTS

3.1/ Capital Cost

The cost of an on-board scale system consists of two components. The load cells, cables, and display unit are a fixed cost. The mounting hardware to adapt the load cells to a particular fifth wheel depend strongly on the make and model of fifth wheel with which the tractor is equipped, and are a variable cost. The delivered cost of both Lodec and SI systems appeared to be essentially similar, about $3500-4000 for a fixed fifth wheel installation, and about $1000 greater for a sliding fifth wheel installation.

3.2/ Installation and Calibration Time

Each system required approximately six hours to install and set up prior to calibration. The systems were purchased as nominally compatible with the particular brand and model of fifth wheel for each truck. However, much of the time involved in installation was consumed by custom fitting to provide proper fifth wheel clearance from the load cells.

Some time was required to travel to the Truck Inspection Station for calibration. Once there, the complete process of measurement and calibration of the truck took about an hour. Depending on the truck's route, there may be some incremental time to return to the Truck Inspection Station with a load. However, the actual trip time with this load is considered to represent revenue time, not calibration time.

3.3/ Data

Data from all four trucks were collected for a period of approximately three months. The number of trips made by each truck varied each day, and in total, as the winter and early spring is not a busy time for aggregate haul. Further, some trucks were down at times for maintenance. The data were carefully reviewed. The majority of the data appeared to be accurate and credible, but a few trips were discarded due to obvious errors in transcription. A total of 277 trips provided reliable data for analysis.

A statistical summary of the data captured from each truck during this experiment is presented in Tables 1 through 4. These tables give the maximum, minimum, average, standard deviation, and coefficient of variation (standard deviation divided by average) of MTO scale axle weight data, MTO gross weight (obtained as a sum of individual axle scale weights), on-board scale readings, the aggregate producers platform scale gross weight, the ratio of aggregate producers gross weight to MTO gross weight, and the ratio of on-board scale reading to MTO scale drive axle load.

Unfortunately, three of the four trucks ended up with their liftable axles set up about 600-700 kg off the desired target of 10 000 kg – two were high and one was low.

Therefore, at the bottom of each table, the axle load statistics are presented again with the load on the liftable axle corrected to an average of 10 000 kg. For each trip, the difference between the average liftable axle load and 10 000 kg was subtracted from the liftable axle load, and that load difference was re-distributed to the tractor axle units and the trailer axle unit.

A composite of data from all four trucks participating in the experiment is presented in Table 5.

A province-wide survey of aggregate truck weights and dimensions was conducted in August 1989, a period during which there was a moratorium on axle weight enforcement against aggregate trucks. This survey captured 276 trucks of the same tractor-tri-axle semitrailer configuration and the same axle spreads and allowable axle loads as the four trucks participating in this experiment. While these trucks were nearly all different, nevertheless they were all very close in dimensions, but each had a slightly different allowable gross weight in the range 51 000-53 000 kg. A number of these trucks had significant deviations in their actual gross weight from their allowable gross weight, both underloaded and overloaded. From Table 5, the standard deviation of allowable gross weight is 1.27% of the allowable gross weight. All trucks in the comparison sample whose actual gross weight differed by more than 3.81% (three times 1.27%) from 100% of their allowable gross weight were therefore discarded. This left a sample of 217 trucks, which as a group are considered closely comparable with the trucks participating in this experiment as represented by Table 5. Because the survey sample has a similar relationship of actual and allowable gross weight as the trucks participating in the experiment, and the same allowable axle loads, it provides a reasonable control group for comparison. A summary of the data from this comparison sample is presented in Table 6. The reason the standard deviation of gross weight in this table is greater than that in Table 5 is because there is a much larger variation in maximum allowable gross weight for the trucks in the survey than there is for the trucks in the experiment.

The frequency distributions for gross weight of all four trucks participating in this experiment, and the comparison sample of similar trucks, is shown in Figure 9. Figures 10, 11 and 12 present similar comparisons between these two groups of trucks for their drive, liftable and trailer axle unit loads, respectively. A graphic composite of the comparative results presented in Figures 9 through 12 is presented in Figure 13.

Table 1/ A. Cupido Transport with Lodec Scale

Measured Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	5 280	5 950	5 799	90	0.016
Drive Axles (kg)	14 470	19 880	17 575	989	0.056
Lift Axle (kg)	7 250	11 310	10 736	445	0.041
Trailer Axles (kg)	14 340	20 286	17 376	1 075	0.062
MTO Gross (kg)	48 851	52 851	51 488	600	0.017
Pit Gross (kg)	49 100	52 830	51 582	557	0.011
On-board Scale (kg)	14 400	19 900	17 553	1 004	0.057
Pit/MTO Gross (%)	98.65	102.47	100.19	0.35	0.003
O-Brd/MTO (%)	89.03	101.56	99.89	1.50	0.015

Corrected Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	5 280	5950	5799	90	0.016
Drive Axles (kg)	1 4845	20255	17950	989	0.055
Lift Axle (kg)	6 514	10574	10000	445	0.045
Trailer Axles (kg)	14 858	20804	17895	1075	0.060

121 trips with 47 potential axle overload charges

Table 2/ Peter Hodge Transport with Lodec Scale

Measured Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	3 980	5 230	4 692	286	0.061
Drive Axles (kg)	15 960	19 430	17 796	809	0.045
Lift Axle (kg)	9 520	10 390	9 992	171	0.017
Trailer Axles (kg)	17 040	21 480	19 174	943	0.049
MTO Gross (kg)	50 330	52 630	51 655	527	0.010
Pit Gross (kg)	50 160	52 440	51 853	474	0.009
On-board Scale (kg)	15 900	19 300	17 797	809	0.045
Pit/MTO Gross (%)	98.37	101.65	100.39	0.76	0.008
O-Brd/MTO (%)	95.99	103.06	100.01	1.25	0.013

Corrected Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	3 980	5 230	4 692	286	0.061
Drive Axles (kg)	15 957	19 427	17 793	809	0.045
Lift Axle (kg)	9 528	10 398	10 000	171	0.017
Trailer Axles (kg)	17 035	21 475	19 169	943	0.049

86 trips with 53 potential axle overload charges

Table 3/ A. Cupido Transport with SI Scale

Measured Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	5 016	6 000	5788	194	0.034
Drive Axles (kg)	15 360	19 130	17503	1178	0.067
Lift Axle (kg)	7 260	10 270	9471	735	0.078
Trailer Axles (kg)	17 430	21 276	18928	1161	0.061
MTO Gross (kg)	49 170	52 960	51690	878	0.017
Pit Gross (kg)	51 070	52 660	51922	442	0.009
On Board Scale (kg)	15 200	18 900	17359	1136	0.065
Pit/MTO Gross (%)	99.43	105.53	100.47	1.40	0.014
O-Brd/MTO (%)	97.34	103.89	99.20	1.22	0.012

Corrected Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	5 016	6 000	5 788	194	0.034
Drive Axles (kg)	15 138	18 908	17 281	1178	0.068
Lift Axle (kg)	7 788	10 798	10 000	735	0.074
Trailer Axles (kg)	17 124	20 970	18 622	1161	0.062

22 trips with 15 potential axle overload charges

Table 4/ Peter Hodge Transport with SI Scale

Measured Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	4 270	5 330	5 071	291	0.057
Drive Axles (kg)	14 820	18 900	16 750	748	0.045
Lift Axle (kg)	10 176	10 920	10 571	170	0.016
Trailer Axles (kg)	17 290	21 410	19 256	941	0.049
MTO Gross (kg)	49 829	53 610	51 648	815	0.016
Pit Gross (kg)	49 610	52 390	51 556	668	0.013
On Board Scale (kg)	15 000	19 200	17 006	704	0.041
Pit/MTO Gross (%)	96.06	101.56	99.83	0.97	0.010
O-Brd/MTO (%)	90.48	104.29	101.56	1.85	0.018

Corrected Data

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	4 270	5 330	5 071	291	0.057
Drive Axles (kg)	15 157	19 273	17 087	748	0.044
Lift Axle (kg)	9 605	10 349	10 000	170	0.017
Trailer Axles (kg)	17 756	21 876	19 722	941	0.048

48 trips with 26 potential axle overload charges

Table 5/ All Trucks with On-Board Scales

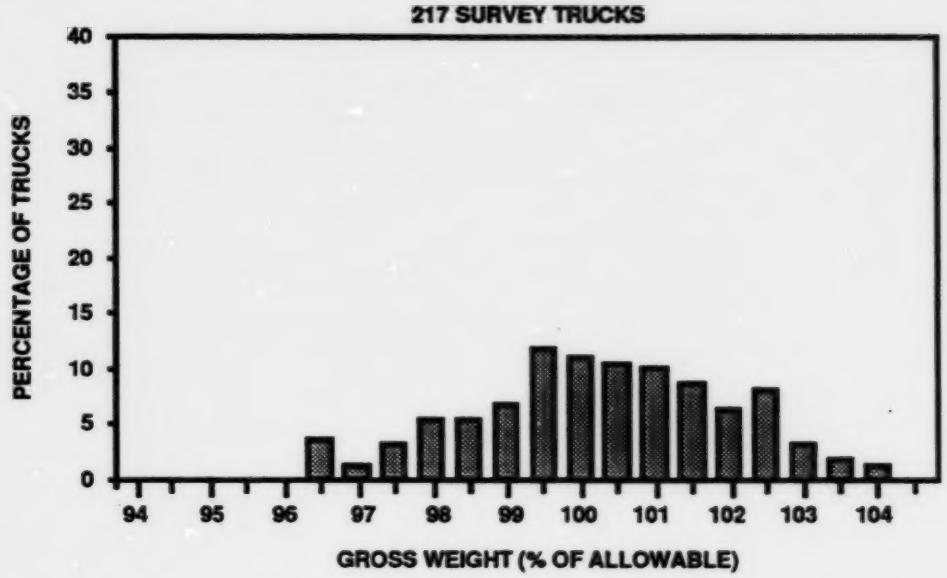
	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	3 980	6 000	5 341	537	0.101
Drive Axles (kg)	14 845	20 255	17 623	1021	0.058
Lift Axle (kg)	6 358	10 798	9 915	396	0.040
Trailer Axles (kg)	14 858	21 876	18 720	1264	0.067
MTO Gross (kg)	48 851	53 610	51 600	656	0.013
Pit Gross (kg)	49 100	52 830	51 689	565	0.011
On Board Scale (kg)	14 400	19 900	17 519	951	0.054
Pit/MTO Gross (%)	96.1	105.5	100.21	0.77	0.008
O-Brd/MTO (%)	89.0	104.3	100.16	1.62	0.016

277 trips with 141 potential axle overload charges (51%)

Table 6/ Comparison Trucks without On-Board Scales

	Minimum	Maximum	Mean	Std Dev	Co Var
Steer Axle (kg)	3 930	6 650	5 126	460	0.090
Drive Axles (kg)	12 020	22 050	17 693	1548	0.087
Lift Axle (kg)	5 180	15 870	9 378	1577	0.168
Trailer Axles (kg)	14 270	26 440	19 705	1798	0.091
MTO Gross (kg)	47 740	53 970	51 902	1012	0.019

217 trucks with 173 potential axle overload charges (80%)



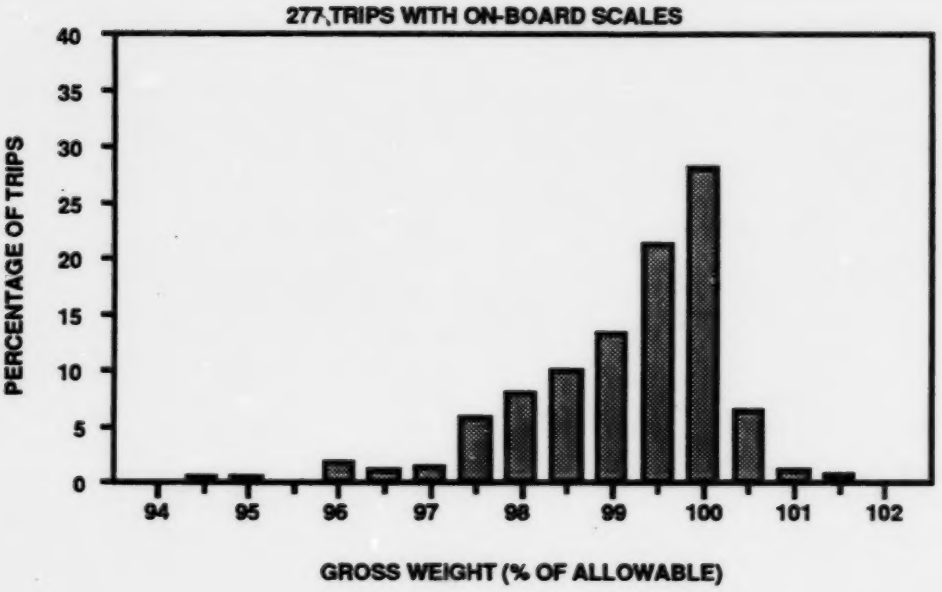
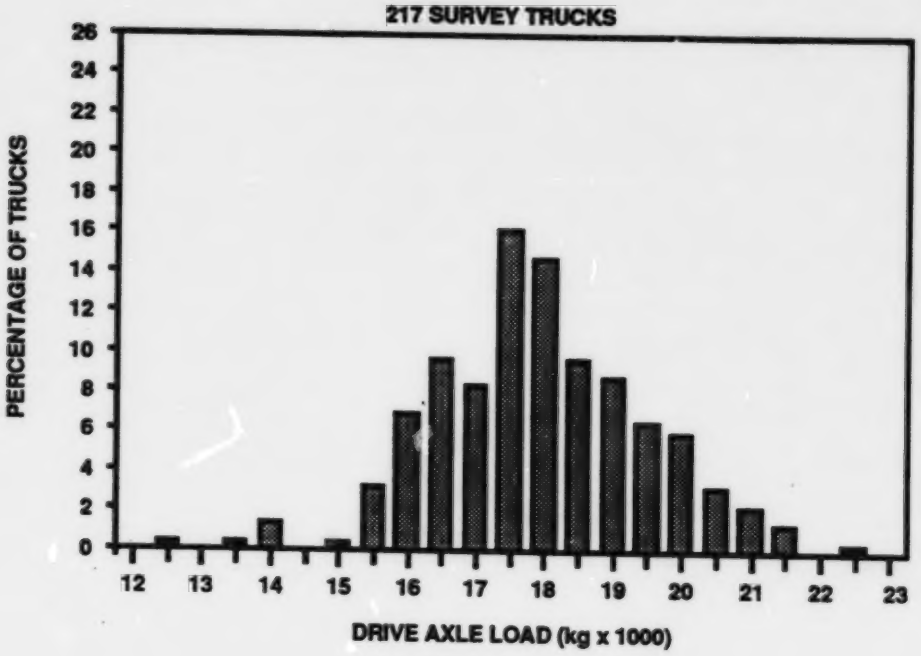


Figure 9/ Distribution of Gross Weight



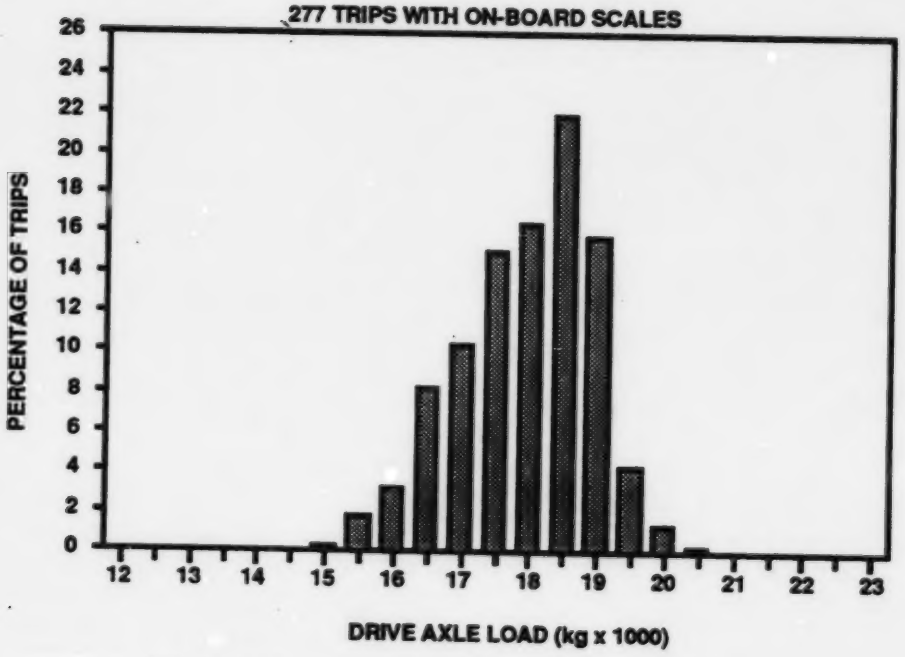
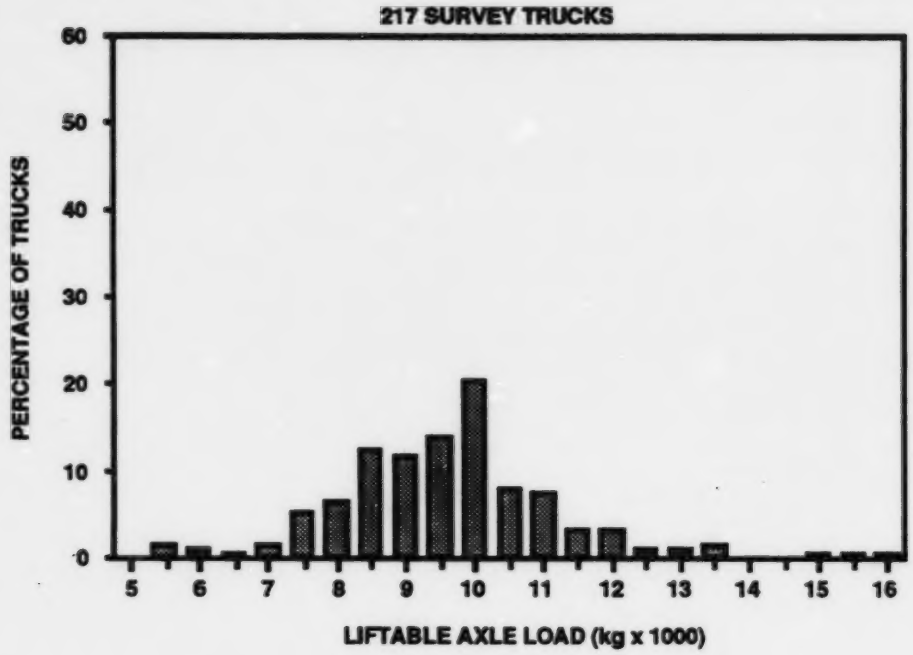


Figure 10/ Distribution of Drive Axle Loads



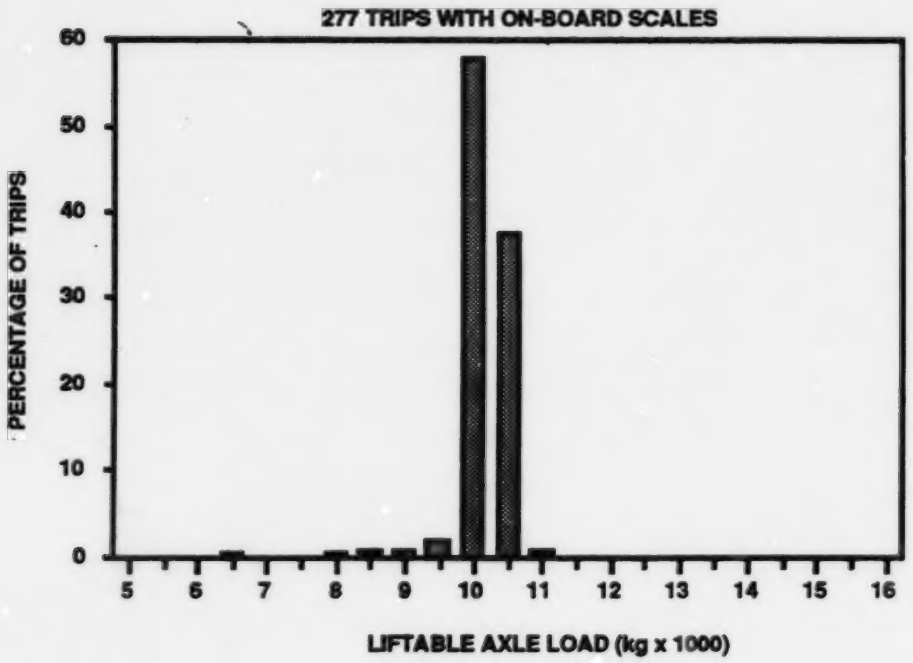
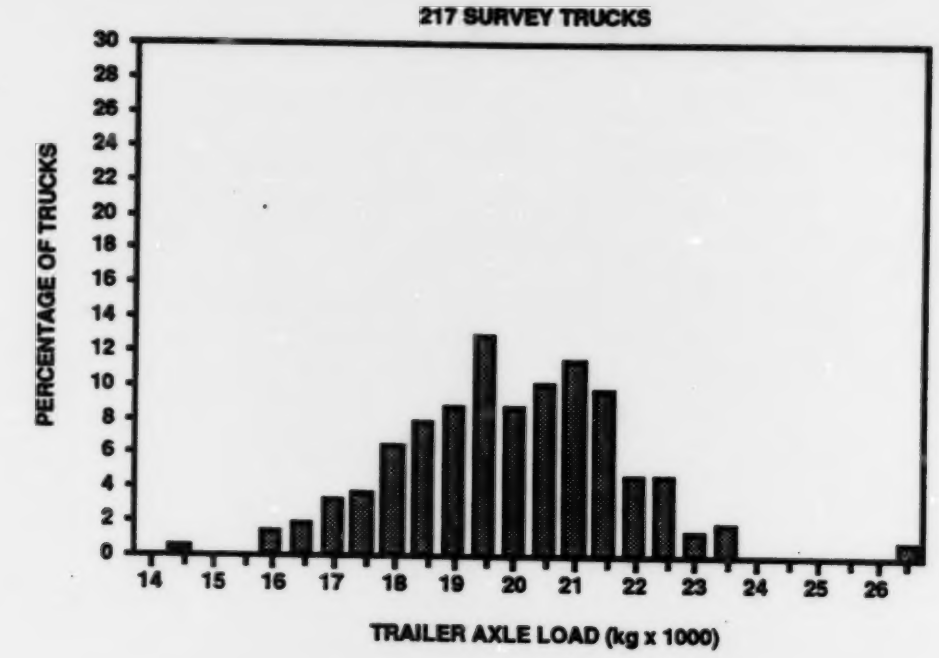


Figure 11/ Distribution of Liftable Axle Loads



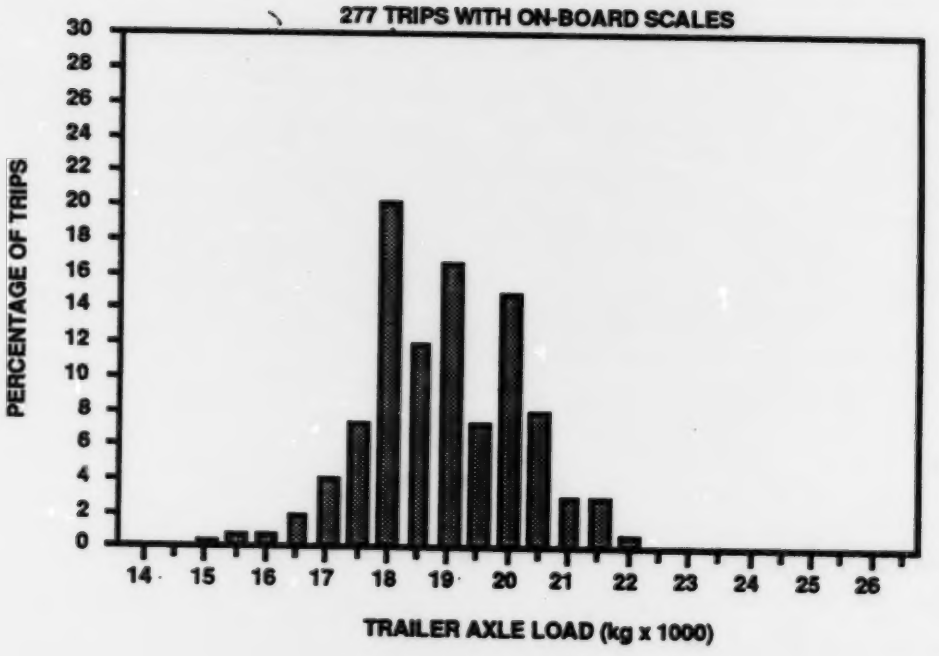


Figure 12/ Distribution of Trailer Axle Loads

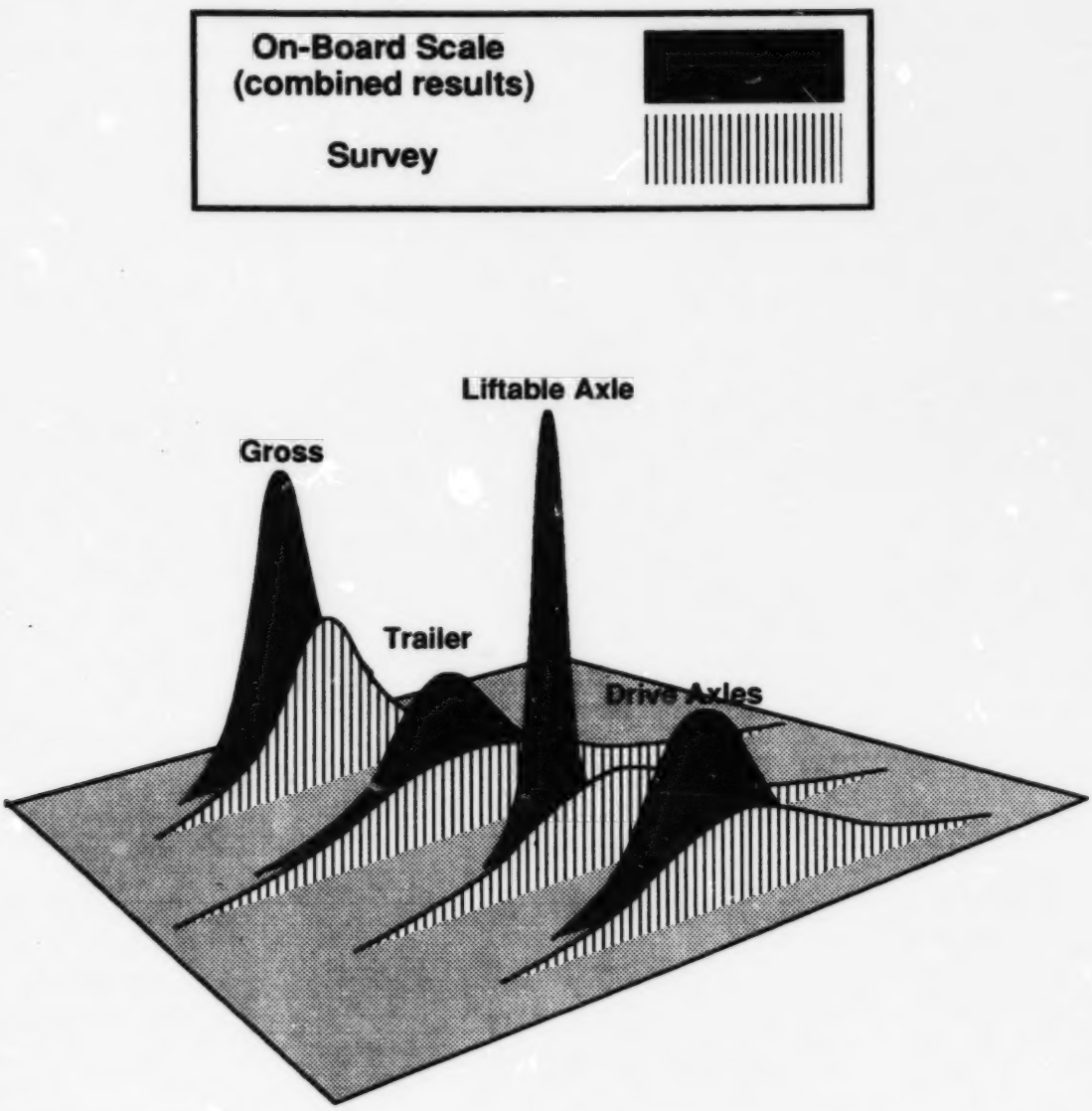


Figure 13/ Distribution of Gross and Axle Loads

4/ DISCUSSION

There was a fair amount of detail work necessary during installation to ensure the fifth wheel had adequate clearance from the load cells and their attachment bolts. This work would be considerably reduced, for example, if the on-board scale systems were engineered for installation during manufacture of the tractor. Installation and calibration could easily be completed within one working day. However, the impact on truck operating schedule can be minimized if the installation is combined with other maintenance work.

Tables 1 through 5 show there was close agreement between the drive-axle load provided by the on-board scales on each truck, and the drive-axle load provided by the ministry multi-platform scale at the Truck Inspection Station. The difference in average values between these two readings is essentially zero for one truck, and about 50 kg for the other three. It is noteworthy that the MTO scale provides a reading to the nearest 10 kg, whereas the on-board scale provides a reading only to 100 kg, so an average difference of about 50 kg would not be unexpected. The results presented here provide confidence that the two models of on-board scale used in this experiment were each essentially as accurate as the MTO scale. They both maintained their accuracy for the duration of the experiment, and there was no discernible difference in their accuracy.

An important part of the experiment was to ensure that the liftable axle on each truck was set up correctly, and was controlled tightly. The first step was to ensure that each truck was equipped with a good quality regulator, whose setting could be locked to prevent drift. The comparison of the distributions of liftable axle loads in Figure 11 shows that this was achieved. The liftable axles on all four trucks held their loads very close to the set load for the duration of the experiment. The standard deviation of liftable axle load for all four trucks in the experiment was about one third that of the comparison sample. This is an area that drivers can easily control. There is no doubt that a good quality locking regulator, careful set-up, and vigilant monitoring of liftable axle load can substantially reduce the number of overloads directly attributable to incorrect load on the liftable axle.

The combination of an accurate gross weight from the aggregate producer's scale, good control of the liftable axle load, and an accurate reading from the on-board scale means simply that the driver has sufficient accurate information to determine whether the truck is in compliance with axle weight law.

It is evident from Table 5 that the aggregate producer's current policies ensure close adherence to maximum allowable gross weight. All four trucks operated at an average gross weight within 0.5% of their maximum allowable gross weight (about 250 kg out of just over 51 000 kg). This is presumably because the aggregate producer requires the driver to dump any overload before the truck is allowed to leave the premises, and may also allow underloads to be "topped up." This latter may have been possible

during this experiment, one of the less-busy times of the year for the aggregate producer, but may not have been so common during the survey period in August, when production would be at its height.

The data in Tables 5 and 6 show that gross weights are not only very close to the maximum allowable, but are also relatively well controlled, as noted above. Since most trucks of the configuration used in this experiment have a sum of allowable axle loads quite close to allowable gross weight, there is very little tolerance in placement of the load if the truck is to comply with axle weight law. A prerequisite in this case is also that the liftable axle is properly loaded. The liftable axle was properly loaded for the trucks participating in this experiment. The average values for drive and trailer axle unit loads were each about 300 kg below the allowable axle load, so on average these trucks were very accurately loaded. However, much of the time, there was actually a drive or trailer axle unit overload, because the load was biased either too far forward, or too much to the rear.

It has been suggested that trailer axle overloads may arise from some load shift rearward when a small amount of load is dumped to reduce a slight gross weight overload. However, the data in Tables 5 and 6 suggest an almost equal likelihood of drive axle or trailer axle unit overload. In the case of an original drive axle overload, any rearward load shift will improve the truck's axle load distribution. An original trailer axle overload is of course exacerbated by any rearward load shift. Drivers are expected to dump very cautiously to trim a small gross weight overload, so it is suggested that any rearward load shift during this phase of operation is unlikely to have a significant effect on the axle load distribution. Therefore, the major issue in axle weight compliance for the trucks that participated in this experiment was simply that the original load was not distributed appropriately for the truck being loaded. It has already been shown that load shift in transit is unlikely to have any significant effect on axle loads [2].

The number of potential axle overload offences is given in Tables 1 through 6. These values are computed using standard ministry policy for charging, and do not represent charges actually laid. In fact, due to the moratorium on axle weight enforcement that applied to aggregate trucks during the period of this experiment, none of the trucks participating in the experiment, or covered by the survey, were charged for an axle overload offence. It is clear that the trucks with the on-board scales have a significantly lower potential rate of axle overload charges than the truck population at large, though the likelihood of a charge remains high. The extent to which the on-board scale contributed to the reduction in potential charges is not clear. It is clear that the much better control of liftable axle load should have had some impact.

Figure 13 provides a graphic comparison of the frequency distribution of gross and axle loads, comparing the data in Tables 5 and 6. The most significant point from Figure 13 is for the liftable axle, which shows that a reliable regulator can produce much more consistent loads than are observed in the population of similar trucks at

large. It also shows at a glance that the other axle loads were also more tightly controlled on the trucks with the on-board scale.

One of the major weaknesses of on-board scales in the British Columbia logging industry has been the vulnerability to foreign object damage of the cables from the load cells to the cab display. The problem was particularly severe for trailer load cells, so that radio telemetry has been used successfully to address poor reliability due to this vulnerability [1]. Recent installations do provide much greater protection, but there is still a need for a connection across the hitch point between the tractor and the trailer. For the tractor-only installations in this experiment, it was possible to provide good protection for the cables, so this source of failure would expect to be much reduced from the experience in B.C., increasing reliability and reducing maintenance expense for the on-board scale system.

This experiment again showed there was close agreement between the gross weight provided by the platform scales of the various aggregate producers from which the trucks originated, and the gross weight obtained by summing the axle loads from the multi-platform scale at the ministry Truck Inspection Station. Differences between pit and MTO scale weights were all well within the discretionary tolerance normally used by inspection staff before a gross weight charge would be laid. These results provide further assurance that weighing conducted by the ministry is consistent with that conducted by the aggregate producers for trade [2].

Because no aggregate producer or carrier was prepared to consider re-distribution of load in the case where the truck was found to be out of compliance with provincial axle weight law, the time and equipment costs that would be associated with any such re-distribution have not been established. The aggregate industry, the producers, and carriers would presumably need to establish these costs before it can develop strategies to ensure a high probability of compliance with axle weight law.

This experiment worked quite simply and well because the tractor-semitrailer required only one additional measurement, beyond the aggregate producer's scale gross weight, in order to determine compliance with provincial axle weight law. This additional measurement was provided by the fifth wheel on-board scale. The scale and load and balance chart were set for evaluation with the liftable axle deployed and loaded to 10 000 kg. It could equally well have been set to work with the liftable axle raised. Either way, the experiment showed quite well that the driver could use the on-board scale to determine compliance with axle weight law. Other truck configurations, such as straight trucks, alone or in combination with some configuration of trailer, are not so easily addressed. These would require either some other form of load measurement, or a more complicated installation. In either case, it would be a more expensive and more difficult task to provide the driver with means to determine compliance with axle weight law than it was for these four tractor-semitrailers.

This experiment has borrowed heavily from technology developed to meet the special needs of the log-haul industry in British Columbia. While the log-haul industry in British Columbia and the aggregate haul industry in Ontario both have to deal rather precisely with the weight of bulk raw materials of low value and somewhat variable density, there are significant and important differences in the two sectors. The Ontario aggregate hauler is weighed at the beginning of the trip and, under current policy of the aggregate producers, cannot get onto the highway with a gross weight overload. In contrast, the B.C. log hauler is weighed at the mill, the end of the trip, and therefore has a requirement to weigh at the loading point to maximize the load while also achieving axle weight compliance. The on-board scale meets this need. The consequence is that in British Columbia use of on-board scales has been accepted because they maximize the load and there is a quick pay-back to the operator for the capital and maintenance cost of the on-board scale. In Ontario, the only use of the on-board scale would be to ensure axle weight compliance. While lower capital and maintenance costs would be expected for on-board scales on Ontario aggregate trucks than for log-haul trucks in British Columbia, the return in Ontario is simply by avoidance of axle overload convictions and corresponding sanctions under the Commercial Vehicle Operator Registration (CVOR) system. Therefore, on-board scales will probably not be nearly as economically attractive to aggregate haulers unless overweight fines are substantially increased and the probability of being caught and convicted of an overweight offence is quite high.

It was identified that the major problem in axle weight control for aggregate trucks is the original load distribution by the loader operator. It is possible that loader operators could do a more reliable job of loading aggregate trucks to produce proper axle weight distribution. It need take no longer than loading takes now. It requires first that the loader operator have some idea of the particular loading needs of the various truck configurations. This is not easy, as there are a very large number of truck configurations, and the load distribution requirements of each are affected significantly by subtle design details and the tare weight distribution. Second, the loader operator needs to be provided with some specific information regarding payload weight and position for each truck. There are a number of measures that could address this need. These have generally already been identified [4]. They include such things as education and training for loader operators and marking on the truck's load box to assist the loader operator, and scales on the loader to weigh the load as it is placed in the truck.

The experiment has shown that the on-board scale allows the driver to determine whether the truck will comply with Ontario's axle weight law. Procedures could also be developed to achieve the same result, using the aggregate producer's platform scale. However compliance is assessed, the truck is already loaded, and the driver has an obligation to bring it into compliance with axle weight law or risk an axle overload charge. There appear to be two choices. Either the driver must dump the whole load and the aggregate producer must re-load the truck, or the load must be redistributed

by some means. Neither of these is attractive, either to the aggregate producer or the trucker.

It appears clearly preferable, therefore, that the loader operator do as good a job as possible in loading the truck properly the first time. Greater efficiency at this stage could improve the turn-around time for trucks, with cost savings for both truckers and producers. The role that on-board scales could play in this is not clear at this time.

5/ CONCLUSIONS

A limited experiment has examined the potential of on-board weighing as a means to improve aggregate truck compliance with provincial axle weight laws. Four tractor-semitrailers from two different aggregate haulers participated in this experiment, in partnership with the ministry. A fifth wheel on-board scale from one of two different vendors was installed on each of these trucks. Axle and on-board scale weight data were gathered over a period of about three months.

It was already known prior to this experiment that aggregates can be shipped within close tolerances to the trucks' maximum allowable gross weight, and that loads do not shift during transit in such a manner as to significantly affect axle loads.

This experiment has demonstrated further that:

- The cost of a fifth wheel on-board scale ranges between $3500 and $5000, depending upon make and model of fifth wheel with which the truck is equipped;
- A fifth wheel on-board scale can be installed and calibrated in 6 to 12 hours;
- The air pressure delivered to a liftable ("belly") axle can be set, and the set pressure can be maintained consistently, if a good quality locking regulator is used;
- Fifth wheel on-board scales can measure drive-axle loads accurately and consistently;
- Fifth wheel on-board scales can be used to determine if a truck is loaded in compliance with axle weight law, provided the liftable axle load is controlled consistently; and
- The fifth wheel on-board scales supplied by the two vendors are essentially equal in most respects.

The trucks participating in this experiment were able to achieve a significantly lower rate of potential axle overload charges than another sample of similar trucks loaded to the same proportion of their allowable gross weight. The extent to which the on-board scales contributed to this achievement is not clear.

The experiment has not addressed either long-term accuracy or reliability of the on-board scales, or the costs that would be associated with re-distribution of load at an aggregate source to produce loads that met both allowable gross and allowable axle loads.

Examination of the data from this experiment shows that :

- Aggregate producers can load trucks consistently within a small tolerance of their allowable gross weight, so that the probability of a charge for a gross weight overload under the ministry's standard charging policy is quite low; and

- Truckers can control loads on liftable axles consistently within a small tolerance of their allowable axle weight, so that the probability of a charge for a liftable axle overload under the ministry's standard charging policy is also quite low.

Given the foregoing two findings, it is concluded that the high proportion of trips on which the trucks participating in this experiment would have potentially risked an axle overload charge is substantially due to the original load placement by the aggregate producer.

The weight obtained from the sum of weights of the ministry multi-platform scales, and the aggregate producers platform scale weight, were in very close agreement for all loads.

REFERENCES

[1] Clark M. and E. Phillips, "On Board Truck Weigh Scales," Paper presented at the Second International Symposium on Heavy Vehicle Weights and Dimensions, Kelowna, B.C., June 1989.

[2] Billing, J.R., "Aggregate Truck Load Shift Experiment," Ministry of Transportation of Ontario, Transportation Technology and Energy Branch, Report CV-90-01, February 1990.

[3] Hutchinson, B.G., F. Nix, R. Green, and R.C.G. Haas, "Evaluation of Allowable Gross Weights for the Aggregate Carrier Industry," University of Waterloo, Report for Government/Aggregate Industry Weight Review Committee, October 1989.

[4] Government/Aggregate Industry Weight Review Committee, Final Report, June 1989.